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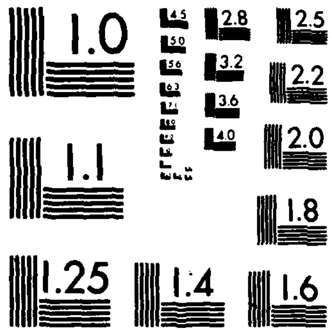
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AD-A143 569

Modified Reflex-Percussive Grooves for Runways

Satish K. Agrawal

April 1984
Final Report

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U.S. Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City Airport, N.J. 08405

NOTICE

Technical Report Documentation Page

1. Report No. DOT/FAA/PM-84/8 DOT/FAA/CT-84/7	2. Government Accession No. AD A143 569	3. Recipient's Catalog No.
4. Title and Subtitle MODIFIED REFLEX-PERCUSSIVE GROOVES FOR RUNWAYS		5. Report Date April 1984
		6. Performing Organization Code
7. Author(s) Satish K. Agrawal		8. Performing Organization Report No. DOT/FAA/CT-84/7
9. Performing Organization Name and Address Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08405		10. Work Unit No. (TRAIS) T1904 A
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Office of Program Engineering Management Washington, D.C. 20590		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Runway surface treatments, such as grooves, can minimize the danger of aircraft hydroplaning by reducing the water buildup on the runway and by facilitating forced water escape from the tire-runway interface. Square saw-cut grooves of 1/4-inch size with spacing between 1 inch and 2 1/2 inches have been widely used, the former providing a higher resistance to hydroplaning. Other surface treatments that have been reported as being effective in minimizing aircraft hydroplaning include porous friction overlay and reflex-percussive grooves. The latter being offered as a cost-effective alternative to square saw-cut grooves.

As the title of this report suggests, the modified reflex-percussive grooves are a derivative of reflex-percussive grooves: the cutting heads for the latter were modified to produce smoother groove edges which tend to improve water flow through the groove channels. Comparative dynamic tests showed that the braking performance of an aircraft tire on modified reflex-percussive grooves is equivalent to the performance on square saw-cut grooves spaced between 1 1/4 inches and 2 inches. Results also showed that hydroplaning was not initiated up to 150 knots speed. The lower cost of the modified grooves makes them a viable cost-competitive method; however, realistic cost estimates and full-savings potential can only be affirmed after application of these grooves in an operational environment.

17. Key Words Runway Grooving Square Saw-Cut Grooves Reflex-Percussive Grooves Braking and Hydroplaning Cost-Effective Alternative	18. Distribution Statement Document is available to the U.S. public through the National Technical Infromation Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	23	

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PREFACE

The work described in this report was undertaken and accomplished by the personnel of the Federal Aviation Administration (FAA) Technical Center. The work request for this research, development, and engineering effort was made by the Office of Airport Standards in the Federal Aviation Administration. Mr. Herman D'Aulerio of the Aircraft Safety and Airport Technology Division provided program direction. The Naval Air Engineering Center at Lakehurst, New Jersey, provided the test facility, test facility operation, and data acquisition system. The test program was conducted under the direction of Mr. Hector Daiutolo of the Federal Aviation Administration Technical Center.

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EXECUTIVE SUMMARY

Since 1976, the Federal Aviation Administration (FAA) Technical Center has been engaged in an experimental program to determine low-cost surface treatment for runways. The surface treatments included in the program were square saw-grooves, reflex-percussive grooves, and porous friction overlay. The program was accomplished in two phases. The first phase was completed in 1980 and consisted of testing on portland cement concrete surfaces. It also included a study to determine the effect of groove spacing on the cost of installing square saw-cut grooves on a runway. The second phase was completed in 1983 and consisted of testing on asphaltic concrete surfaces.

The technical program was conducted at the test facilities of the Naval Air Engineering Center, Lakehurst, New Jersey. Test speeds of up to 150 knots were achieved by the use of a jet-powered pusher car guided on steel rails. Test were conducted in the speed range of 70 to 150 knots using a Boeing 727 aircraft tire under operating conditions whose magnitudes represented main landing gear assembly values typical of heavy jet aircraft during landing and rollout. Rainfall accumulation was represented by water conditions classified as wet, puddled, and flooded. The results of phase one and part of phase two of the program were published as FAA Reports DOT/FAA/RD-80/78 and DOT/FAA/RD-82/77. This document is the last report in the program.

The overall conclusion from the FAA program can be summarized as follows:

Low-cost surface treatment for runways can be provided in two ways: (1) by increasing the spacing of the square saw-cut grooves beyond 1 1/4 inches, and (2) by installing modified reflex-percussive grooves. In each case, the braking effectiveness of an aircraft tire is "acceptable" and incipient hydroplanning is delayed to a speed beyond 150 knots. While the cost savings available as a result of increased groove spacing may be up to 25 percent, the potential savings of up to 50 percent can be obtained by installing the modified reflex-percussive grooves on runways. However, realistic savings potential of the modified reflex-percussive grooves can only be confirmed after application of these grooves in an operational environment.

INTRODUCTION

BACKGROUND.

Runway grooving has been recognized as an effective surface treatment that minimizes aircraft hydroplaning. The grooves are normally cut by diamond-tipped rotary saws. Various groove configurations have been suggested for the runway; however, square grooves of 1/4-inch size with spacing between 1 inch and 2 1/2 inches have been widely used, the former providing a higher resistance to hydroplaning. Recently, a few runways have been grooved at a spacing of 3 inches. Other surface treatments that have been reported as being effective in minimizing aircraft hydroplaning include porous friction overlay and grooves produced by reflex-percussive cutting process. The latter being offered as a cost-effective alternative to square saw-cut grooves.

The reflex-percussive process employs multi-edged cutting heads to produce nonsymmetrical v-grooves. These grooves are in an experimental stage; however, the Federal Aviation Administration (FAA) has demonstrated their cost-effectiveness in portland cement concrete (pcc) surface by full-scale tire braking tests under controlled dynamic conditions (reference 1). The installation of these grooves in asphaltic concrete surface was less successful during the first attempt (reference 2). The primary reason being the decrease in the reflex action of the percussive process in viscoelastic asphaltic concrete. As a result, the groove channels were less smoother than in pcc; and the effectiveness of the grooves in providing braking action to an aircraft tire on water covered surfaces was equivalent to square saw-cut grooves spaced at 3 inches and to the porous friction overlay.

In order to use the full cost-saving potential of the reflex-percussive grooving process, the cutting head had to be modified. The original developer of these grooves - Klarcrete Limited - designed a new cutting head which was cylindrical in shape and the cutting edge was 1/8-inch thick. The continuous cutting edge provides overlapping strokes that tend to produce a smoother groove channel. Consequently, this research was undertaken to determine if the modified percussive grooves will provide acceptable performance and a cost-effective alternative to the square saw-cut grooves.

OBJECTIVE.

The objective of the testing described in this report is to compare the braking and hydroplaning performance of an aircraft tire on asphaltic concrete surface having the modified reflex-percussive grooves and saw-cut grooves.

TESTING APPROACH

The magnitude of the coefficient of friction, as computed by dividing the tangential forces developed at the tire-runway interface by the vertical load on the tire, determines the relative braking performances of the surfaces tested. Hydroplaning behavior, however, is quantified in an indirect manner. The coefficient of friction approaches zero at hydroplaning, but the presence of small viscous and mechanical drags during hydroplaning makes it difficult to identify the speed at which the friction coefficient is zero. Thus, a direct measurement of hydroplaning

speed is difficult. Various indirect methods have been used in the past (reference 3) to identify the onset of hydroplaning. In the present study, incipient hydroplaning is indicated when the measured coefficient of friction is 0.05 or lower. In comparison, the average coefficient of friction between the aircraft tire and the dry runway is approximately 0.7 during landing.

There are two methods by which a meaningful comparison of the braking performance of an aircraft tire on various surface treatments can be accomplished: (1) measurement of coefficient of friction when the tire is locked and slides over the test surfaces, or (2) measurement of maximum value of the available coefficient of friction on each test surface. This study employs the second method, even though it requires a large number of tests. The disadvantage with the first method is an accelerated treadwear of the tire which may require frequent tire changes; danger of tire blowout is also present in the first method. The second method represents a realistic reproduction of the braking process of an aircraft.

As in earlier test programs (references 1 and 2), the maximum value of available friction coefficient for a given set of operating conditions was obtained by conducting many tests. The tests were conducted at gradually increasing brake pressure settings. In each test, the magnitudes of the friction coefficient and changes in tire angular velocity (a measure of tire circumferential slip) were monitored. Initially, both the coefficient and the circumferential slip would increase with brake pressure. Beyond a slip of about 15 percent, the friction coefficient would start to drop and eventually be reduced to locked-wheel level. Thus, by monitoring both the friction level and the magnitude of slip in successive tests, it was possible to identify the maximum available friction level for a given set of operating conditions.

EXPERIMENTAL PROGRAM

The experimental program was conducted at track No. 3 of the Naval Air Engineering Center, Lakehurst, N.J. The track is 1 1/4 miles long and has guide rails spaced 52 1/4 inches apart, running parallel to the track centerline. Reinforced concrete strips extending beyond the guide rails to a width of 28 feet also run parallel to the track. The last 144 feet of the track contained the test bed. The test bed was 2 1/2 inches thick and 30 inches wide and was made of asphaltic concrete.

The major components of the test equipment are: (1) a four-wheeled jet car, (2) a dead-load carriage which supports the dynamometer and wheel assembly, (3) and the measurement system. The jet car (figure 1) is powered with four J48-P-8 aircraft engines developing a total thrust of 24,000 pounds. The jet car is used to propel the dynamometer and wheel assembly and the carriage from the launch end at a preselected speed. The car is disengaged after the test speed is attained, and the dynamometer assembly and the carriage are allowed to coast at this speed into the test bed.

The dynamometer and wheel assembly was designed and fabricated by the FAA and has the capability of simulating a jet transport tire-wheel assembly under touchdown and rollout conditions. The dynamometer is similar in design to one developed by the National Aeronautics and Space Administration (NASA) for the Langley Test Facility (reference 4). Figure 2 shows the dynamometer and wheel assembly and the details of the instrumentation for measuring vertical and horizontal loads at the axle. The assembly is pivoted about an axis contained in the dead-load carriage.

TEST SECTIONS.

The 144-foot test bed was divided into four 36-foot sections (figure 3). The dimensional tolerance of the asphaltic test bed was held within ±3/32-inch from horizontal level. The first two sections contained the reflex-percussive grooves produced by the modified cutting head; the other two contained 1/4-size square grooves at spacings of 1 1/4 inches and 2 inches. Figure 4 shows the two types of grooves in the test bed. Dimensions of the grooves are shown in figure 5; figures 6 and 7 show the groove installation machines. Figure 8 shows the original and the modified cutting head for installing the reflex-percussive grooves in asphaltic concrete.

TEST PARAMETERS.

The operational parameters were selected to represent main landing gear assembly values typical of heavy jet aircraft during landing and rollout. The environmental parameters included water accumulation representative of light to moderate rain.

The following is a summary of the test parameters:

Operational Parameters

Tire:	Vertical Load	- 35,000 pounds
	Inflation Pressure	- 140 pounds/square inch
	Tread Design	- worn
	Size/Type	- 49x17, 26-ply, type VII
Pavement:	Type	- asphaltic concrete
	Texture	- 0.015 (nongrooved)
	Surface Treatments	- reflex percussive grooves 20° groove angle; 3-inch spacing
		- square saw-cut grooves 1/4-inch size; 1 1/4-inch and 2-inch spacings
Aircraft:	Speed	- 70 knots to 150 knots
	Wheel Operation	- rolling to locked wheel
	Brake Pressure	- 200-2200 pounds/square inch

Enviromental Parameters

	Light Rain	- wet: water depth less than 0.01 inch
	Moderate Rain	- Puddled: water depth of 0.10 inch

TEST PROCEDURE.

The dynamometer assembly, with mounted tire, was positioned at the launch end of the track for the test. A complete braking test consisted of the following steps:

1. Water depth was set on the test sections at the recovery end.

2. Jet engines were started at the launch end and set at the performance level to provide the preselected speed in the test section.

3. Jet car was released to propel the test equipment (dead-load carriage and dynamometer assembly). The test tire remained in free-rolling mode.

4. Jet car was braked and separated from the test equipment several hundred feet ahead of the test bed. This allowed the dead-load carriage and dynameter assembly to enter the first test section at the preselected speed. The speed decayed by 1 to 2 knots in the remaining sections.

5. Before the dynamometer assembly entered the first section, the hydraulic systems were activated to apply the vertical load and brake pressure on the tire.

6. The wheel entered the test sections at preselected test conditions. The instrumentation was activated and the data were recorded.

7. As the wheel left the test bed, unloading and brake release were initiated and the test equipment was recovered by the use of arresting cables.

DATA COLLECTION AND ANALYSIS

The automatic data handling system is a multichannel analog recording system which utilizes standard FM/FM telemetry for transmission of data from the moving dead-load carriage. Both low- and high-level signals are frequency multiplexed for recording on a single magnetic tape. Recovery of these data in analog form permits an early validation and review of the dynamic data for further testing purposes.

A typical data trace is shown in figure 9. Table 1 shows the results on the asphaltic concrete sections. The coefficients of friction in this table are the maximum available under each set of operating conditions; many more tests were conducted to obtain the maximums. A least square fit was obtained between speed and coefficient of friction (table 1).

DISCUSSION

This investigation included wet and puddled water conditions only. Wet conditions are normally encountered during or after a light or moderate rain. These surfaces may be saturated with water but would not have measurable water depth present on them. The puddled surfaces are representative of conditions that can be expected immediately after heavy rains of short duration.

The physical description of the water removal action in the tire-runway interface was discussed in reference 2. The results presented in this report also support that description. The braking performance of the worn tire on wet surface is shown in figure 10. A single curve has been drawn for all the data because of the fact that the available friction level for all the treatments is high for the entire range of test speeds. Thus, an aircraft equipped with worn tires will have excellent braking (on a wet surface with any of the groove patterns studied) throughout its landing and rollout maneuvers, and the available friction levels are insensitive to the type of surface treatment included in the study.

TABLE 1. FRICTION - SPEED DATA

LEAST SQUARES PROBLEM

NO. OBSERVATIONS 14
POLY. DEGREE 2

COEFFICIENTS

0	0.36780E 02
1	0.53487E-01
2	-0.76476E-03

WORN TIRE/WET SURFACE

TREATMENTS:

A - 1 1/4 INCH SPACING

B - 2 INCH SPACING

C - MODIFIED REFLEX PERCUSSIVE GROOVES

COEFFICIENT OF FRICTION X 100

POINT	SPEED, KNOTS	MEASURED	CALCULATED	DIFFERENCE	TREATMENT
1	0.70000E 02	0.33000E 02	0.36777E 02	-0.37769E 01	C
2	0.70000E 02	0.35000E 02	0.36777E 02	-0.17769E 01	C
3	0.70000E 02	0.39000E 02	0.36777E 02	0.22231E 01	B
4	0.70000E 02	0.40000E 02	0.36777E 02	0.32231E 01	A
5	0.10900E 03	0.34000E 02	0.33524E 02	0.47589E 00	A
6	0.10900E 03	0.34000E 02	0.33524E 02	0.47589E 00	B
7	0.10900E 03	0.36000E 02	0.33524E 02	0.24759E 01	B
8	0.11100E 03	0.30000E 02	0.33295E 02	-0.32946E 01	C
9	0.13900E 03	0.29000E 02	0.29439E 02	-0.43890E 00	B
10	0.14000E 03	0.28000E 02	0.29279E 02	-0.12790E 01	A
11	0.14100E 03	0.29000E 02	0.29118E 02	-0.11761E 00	C
12	0.14100E 03	0.29000E 02	0.29118E 02	-0.11761E 00	C
13	0.14100E 03	0.30000E 02	0.29118E 02	0.88239E 00	B
14	0.14200E 03	0.30000E 02	0.28955E 02	0.1045[illegible]E 01	C

ERR**2 = 0.53918E 02 STD ERR 0.2[illegible]

TABLE 1. FRICTION - SPEED DATA (Continued)

LEAST SQUARES PROBLEM

NO. OBSERVATIONS 16
POLY. DEGREE 2

WORN TIRE/PUDDLED SURFACE

TREATMENTS:

A - 1 1/4 INCH SPACING

B - 2 INCH SPACING

C - MODIFIED REFLEX PERCUSSIVE GROOVES

COEFFICIENTS

0	0.93076E 02
1	-0.12521E 01
2	0.47055E-02

COEFFICIENT OF FRICTION X 100

POINT	SPEED, KNOTS	MEASURED	CALCULATED	DIFFERENCE	TREATMENT
1	0.70000E 02	0.25000E 02	0.28486E 02	-0.34861E 01	C
2	0.71000E 02	0.31500E 02	0.27898E 02	0.36025E 01	A
3	0.72000E 02	0.25000E 02	0.27318E 02	-0.23183E 01	C
4	0.72000E 02	0.33000E 02	0.27318E 02	0.56817E 01	B
5	0.74000E 02	0.24000E 02	0.26188E 02	-0.21881E 01	C
6	0.89000E 02	0.18000E 02	0.18912E 02	-0.91159E 00	C
7	0.89000E 02	0.17000E 02	0.18912E 02	-0.19116E 01	C
8	0.10800E 03	0.12500E 02	0.12734E 02	-0.23445E 00	C
9	0.10900E 03	0.11000E 02	0.12503E 02	-0.15035E 01	B
10	0.11000E 03	0.14500E 02	0.12282E 02	0.22181E 01	A
11	0.11100E 03	0.13000E 02	0.12070E 02	0.93032E 00	C
12	0.12900E 03	0.11000E 02	0.98597E 01	0.11403E 01	A
13	0.13400E 03	0.10000E 02	0.97870E 01	0.21300E 00	C
14	0.13600E 03	0.11000E 02	0.98238E 01	0.11762E 01	A
15	0.13800E 03	0.85000E 01	0.98982E 01	-0.13982E 01	C
16	0.14000E 03	0.90000E 01	0.10010E 02	-0.10103E 01	B

ERR**2 = 0.85866E 02 STD-ERR = 0.25700E 01

The braking performance of the worn tire on puddled surfaces with saw-cut grooves and modified reflex-percussive grooves is shown in figure 11. This figure shows that the 1 1/4-inch spaced grooves provide higher friction levels than the other grooves. In order to evaluate the improvement provided by the modified cutting head for the reflex-percussive grooves over the standard cutting head used in the previous study (reference 2), data from reference 2 are replotted in figure 12. Some of the important features reflected in figures 11 and 12 are discussed below.

The most distinct feature is the shift in the coefficient of friction curve for the reflex-percussive grooves: the performance curve with the modified cutting heads lies in the shaded area bounded by the performance curves for square saw-cut grooves spaced at 1 1/4 inches and 2 inches.

Another important feature that is reflected in the two figures is a high degree of repeatability: the separation between the performance curves for saw-cut grooves is nearly identical, particularly in the high speed range, even though the tests were conducted at different times and on different tests beds. However, the absolute magnitudes are not identical because of the variations in the asphalt mixes and resulting surface textures, and a different tire.

Though, the braking performance of an aircraft tire on puddled surfaces is represented by individual curves for various surface treatments (figure 11), it may not be unreasonable to draw a single line to show the performance of the two types of grooves (figure 13). The data scatter is small, particularly in the 90 to 150 knots speed range.

It is interesting to note that the slope of the friction-speed curve in figure 13 is changing assymptotically beyond 140 knots and below 70 knots. The implication is that where a landing is attempted at a higher than normal speed, the wheels will not immediately experience a state of hydroplaning. Similarly, as the aircraft is being braked and going through successively lower speeds, it is encountering a gradually increasing rate of change of friction level. This results in a shorter overall stopping distance than if the friction-speed curve were flat.

It is clear from figures 10 and 13 that both type of surface treatments included in this investigation perform similarly. In both wetness conditions the friction levels are above the hydroplaning level. The modified reflex-percussive grooves provide braking performance nearly equivalent to the saw-cut grooves spaced between 1 1/4 inches and 2 inches. The lower cost of the reflex-percussive grooving process makes it a viable cost competitive method. However, realistic cost estimated and full savings potential can only be affirmed after application of these grooves in an operational environment.

CONCLUSION

It is concluded from the findings of this research that the modified reflex-percussive grooves provide braking performance nearly equivalent to saw-cut grooves spaced between 1 1/4 inches and 2 inches. The lower cost of the modified reflex-percussive grooves makes it a viable cost competitive method; however, realistic-cost estimates and full-savings potential can only be affirmed after application of these grooves in an operational environment.

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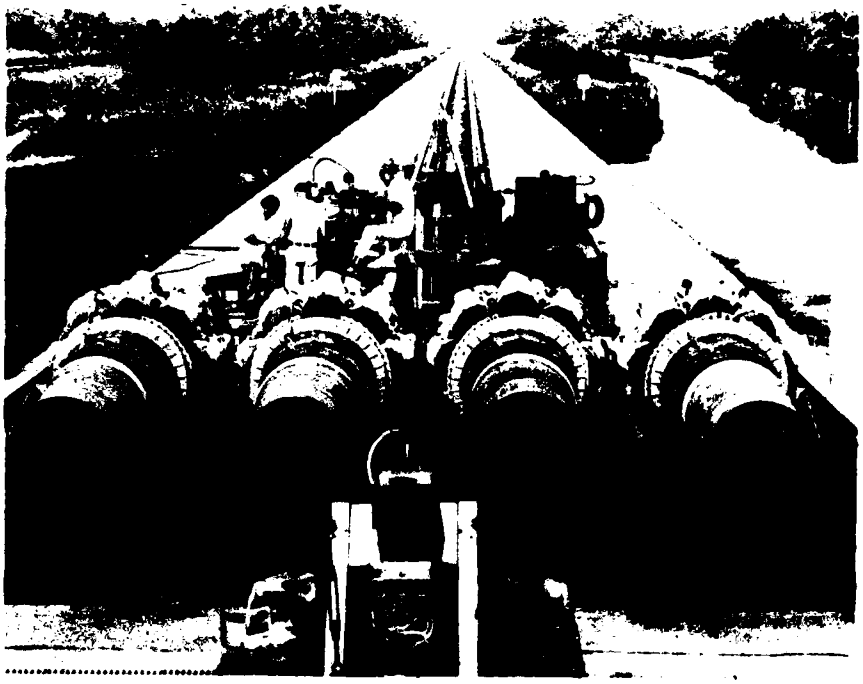

FIGURE 1. JET-POWERED PUSHER CAR FOR PROVIDING PRESELECTED SPEEDS TO TEST EQUIPMENT

FIGURE 2. DYNAMOMETER AND WHEEL ASSEMBLE SHOWING VERTICAL AND HORIZONTAL LOAD LINKS

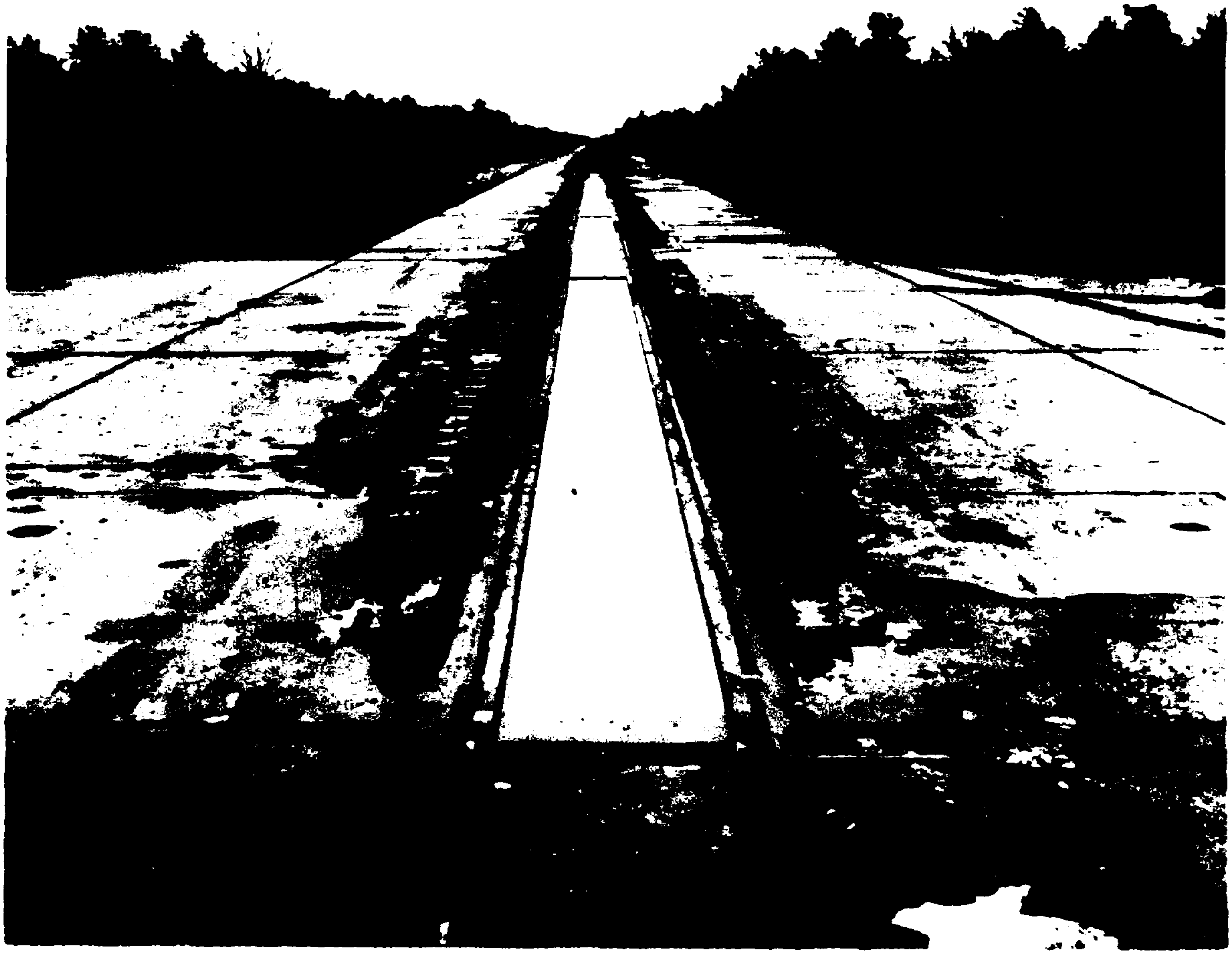

FIGURE 3. 144-FOOT TEST BED AT THE END OF THE TEST TRACK

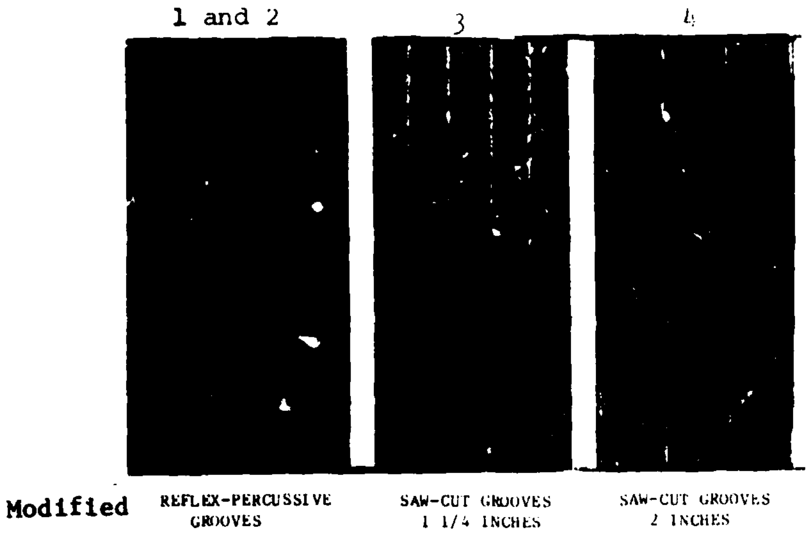

FIGURE 4. VARIOUS TEST SECTIONS OF THE 300-FOOT ASPHALTIC CONCRETE TEST BED (EACH SECTION IS 40 FEET LONG)

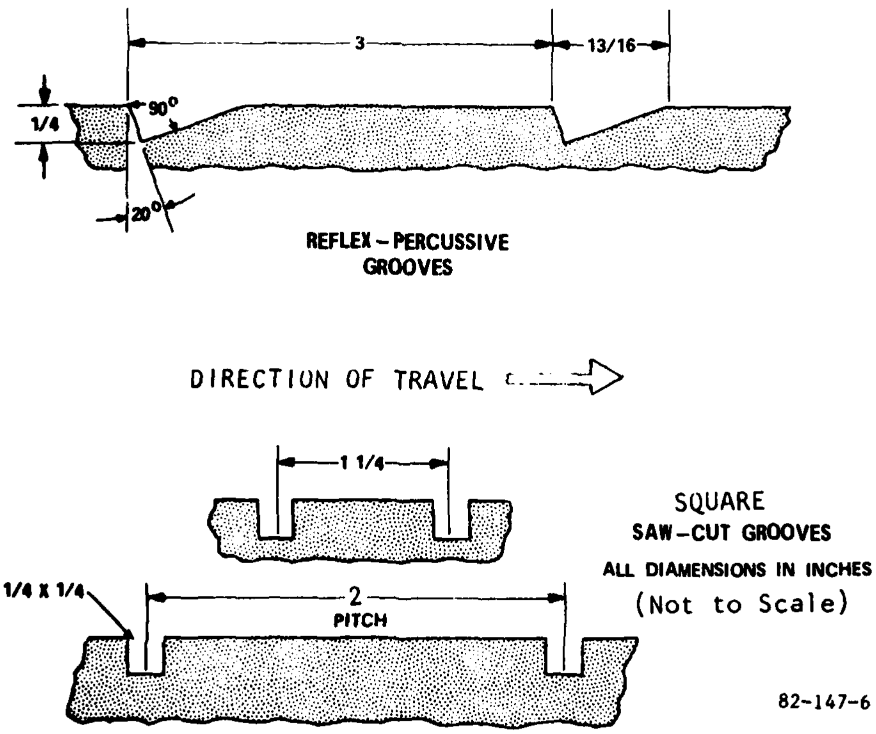

FIGURE 5. DIMENSIONS OF REFLEX-PERCUSSIVE GROOVES AND CONVENTIONAL SAW-CUT GROOVES

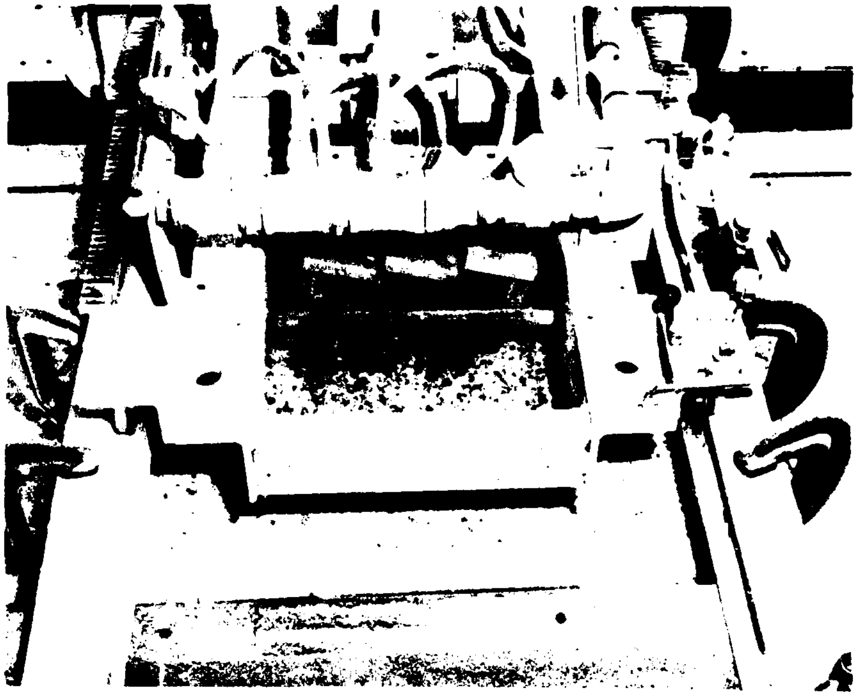

FIGURE 6. MACHINE FOR INSTALLING REFLEX-PERCUSSIVE GROOVES IN THE TEST SECTIONS

FIGURE 7. MACHINE FOR INSTALLING SAW-CUT GROOVES IN THE TEST SECTIONS

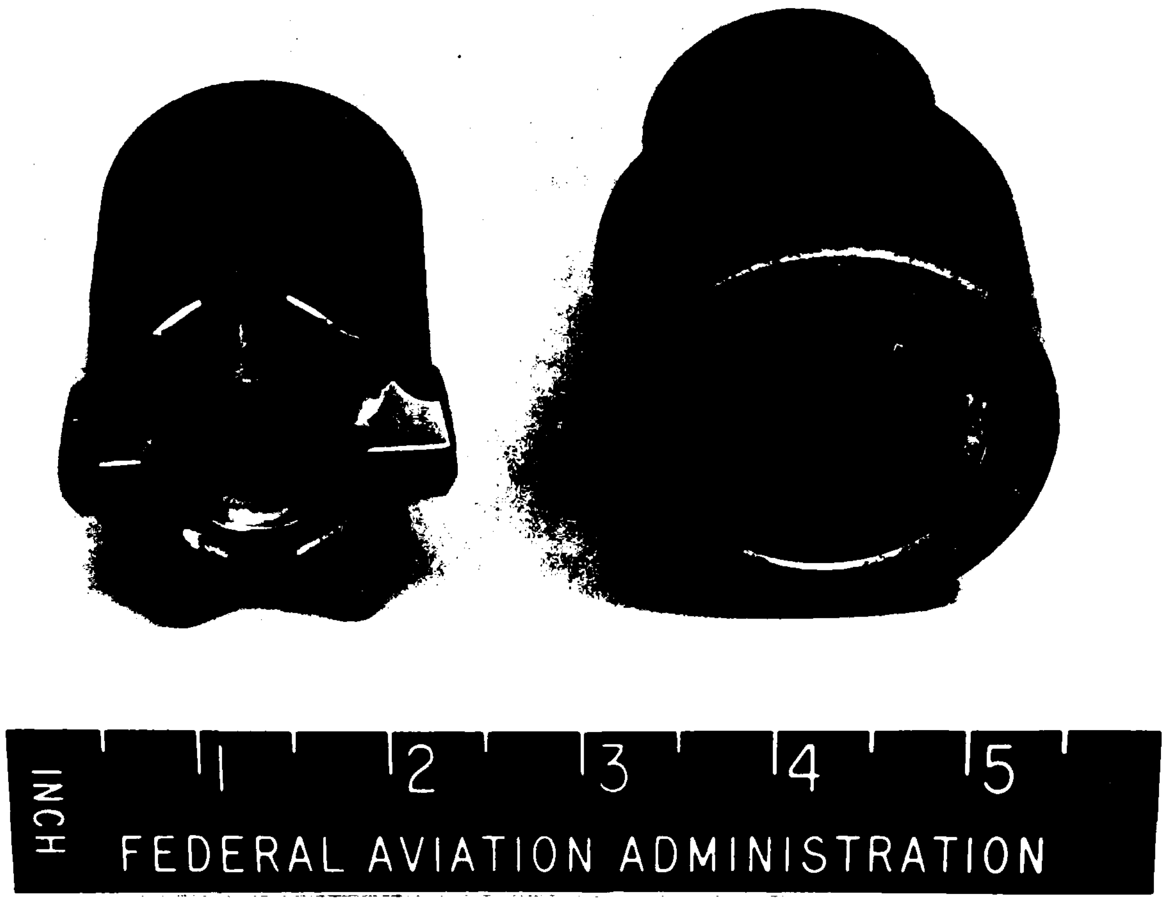

FIGURE 8. THE ORIGINAL AND MODIFIED CUTTING HEAD FOR INSTALLING REFLEX-PERCUSSIVE GROOVES

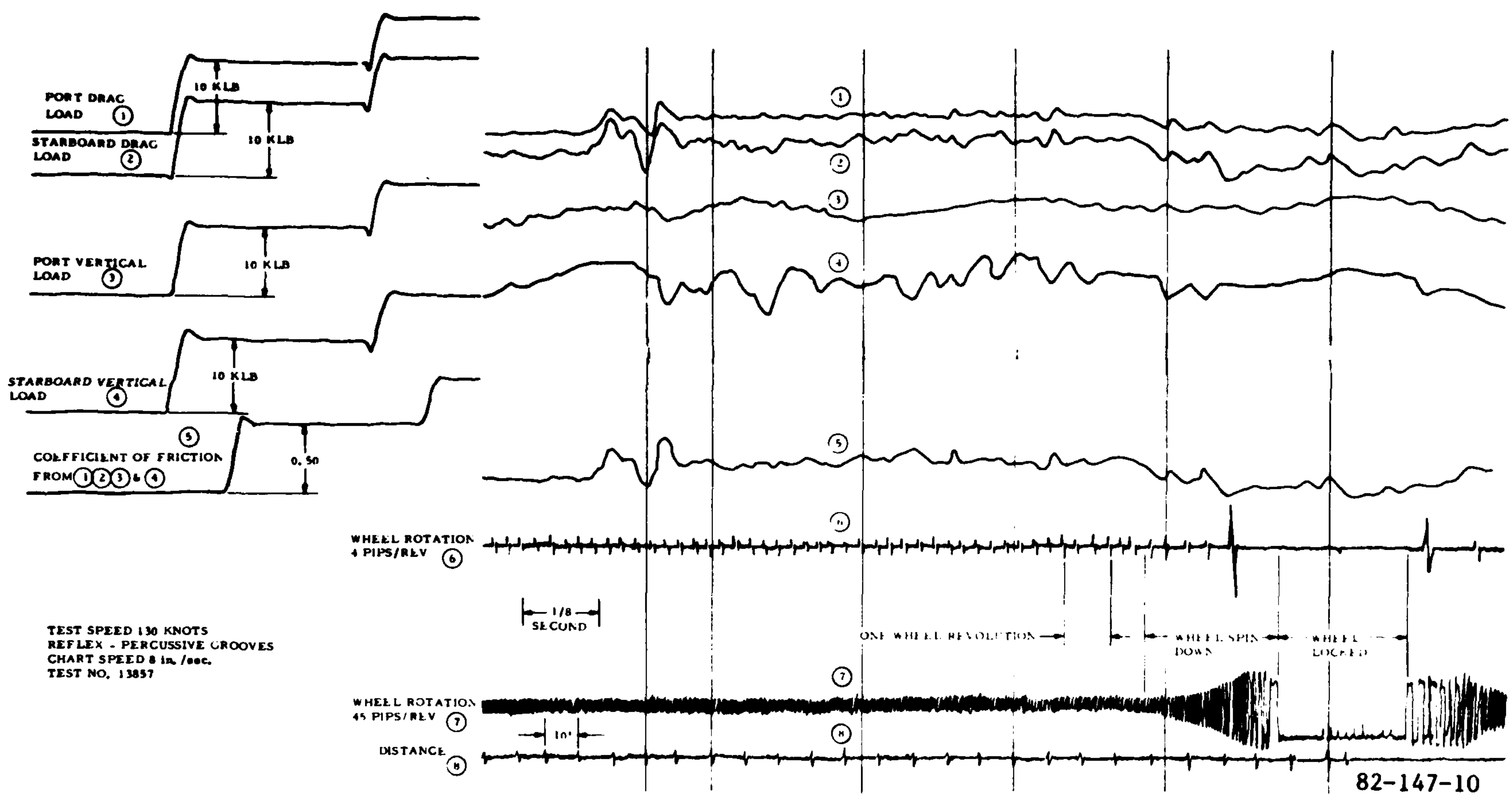

FIGURE 9. A TYPICAL DATA TRACE FOR A BRAKING TEST

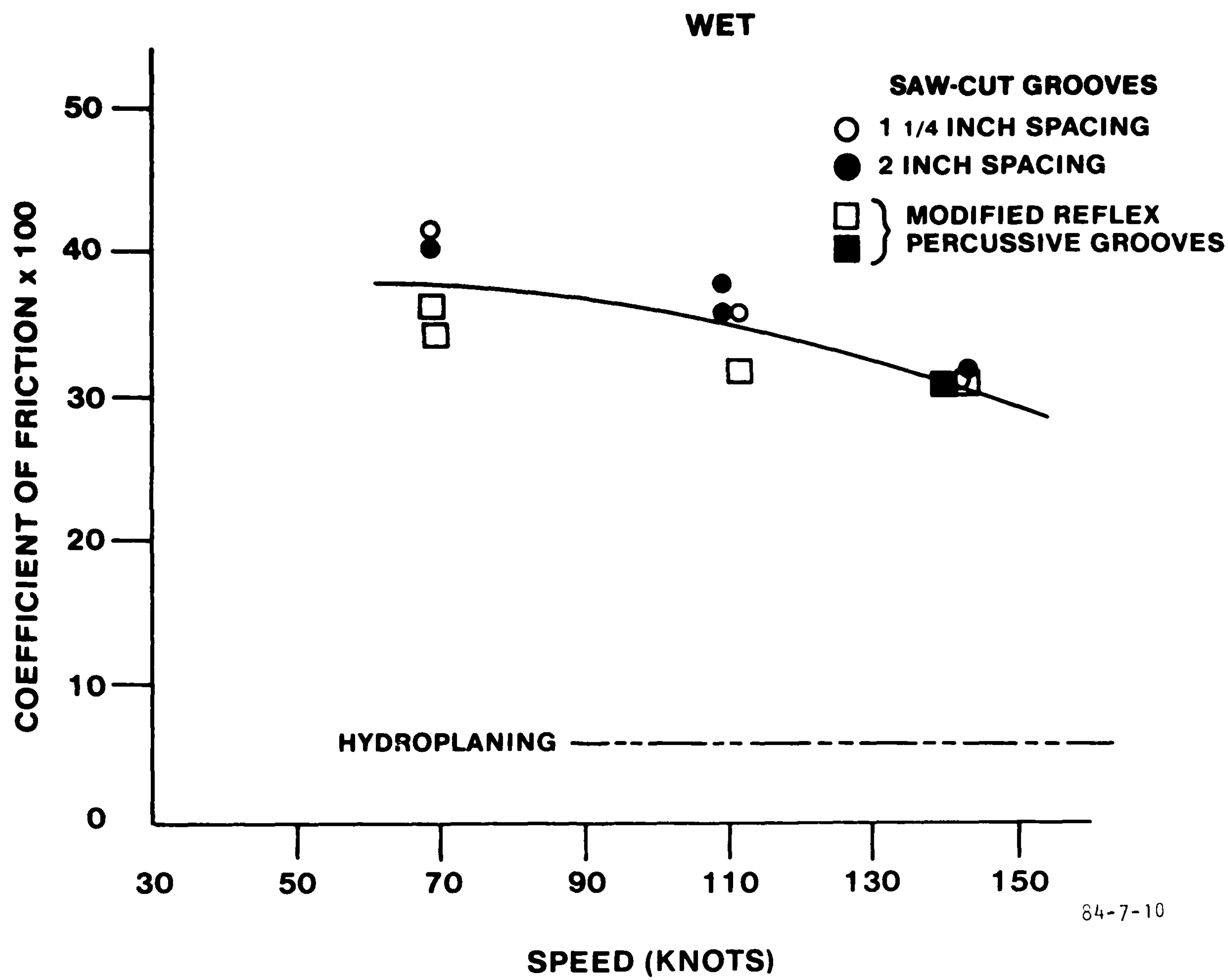

FIGURE 10. BRAKING PERFORMANCE OF A WORN TIRE ON WET SURFACES

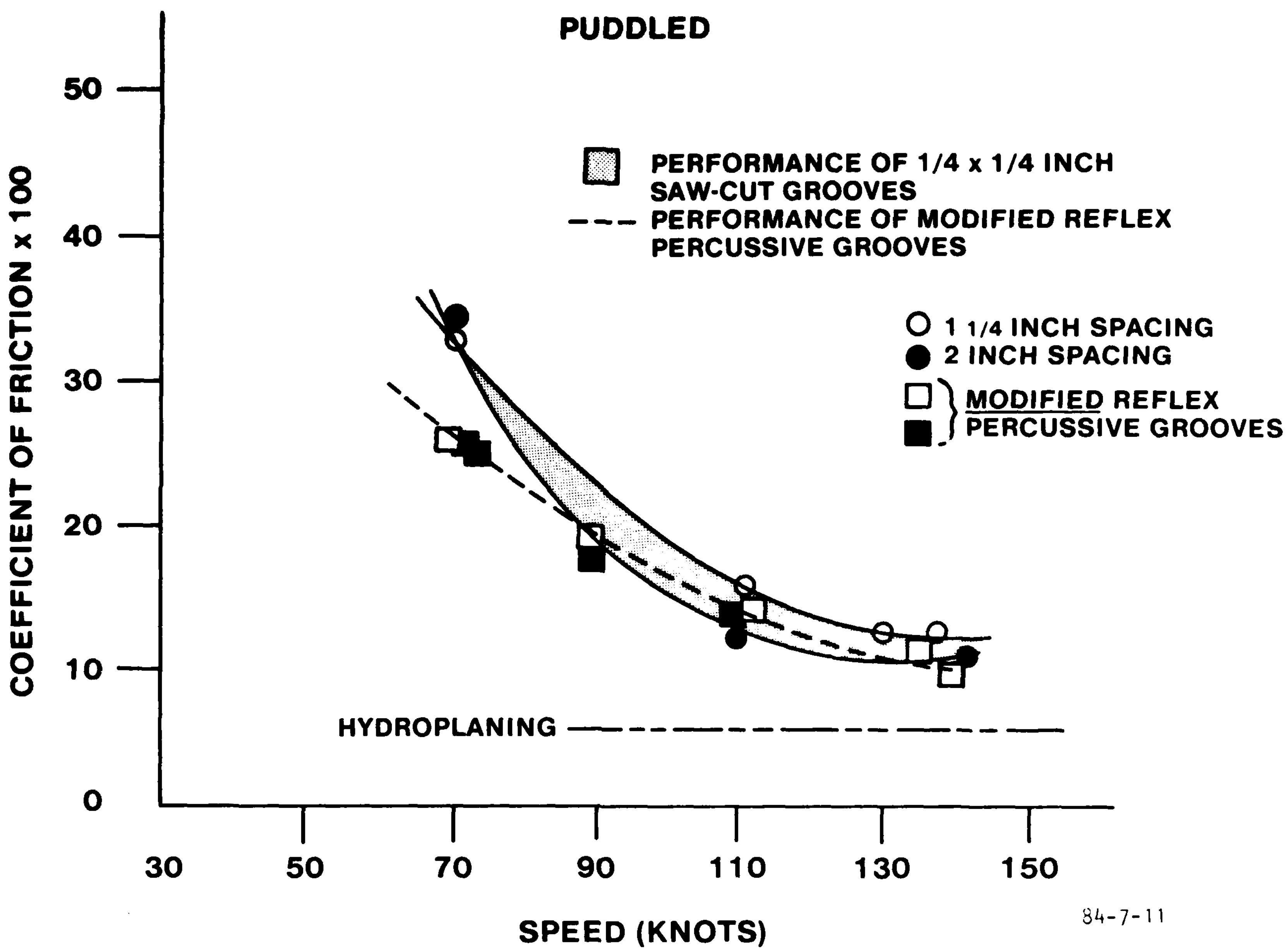

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FIGURE 11. BRAKING PERFORMANCE OF A WORN TIRE ON PUDDLED SURFACES

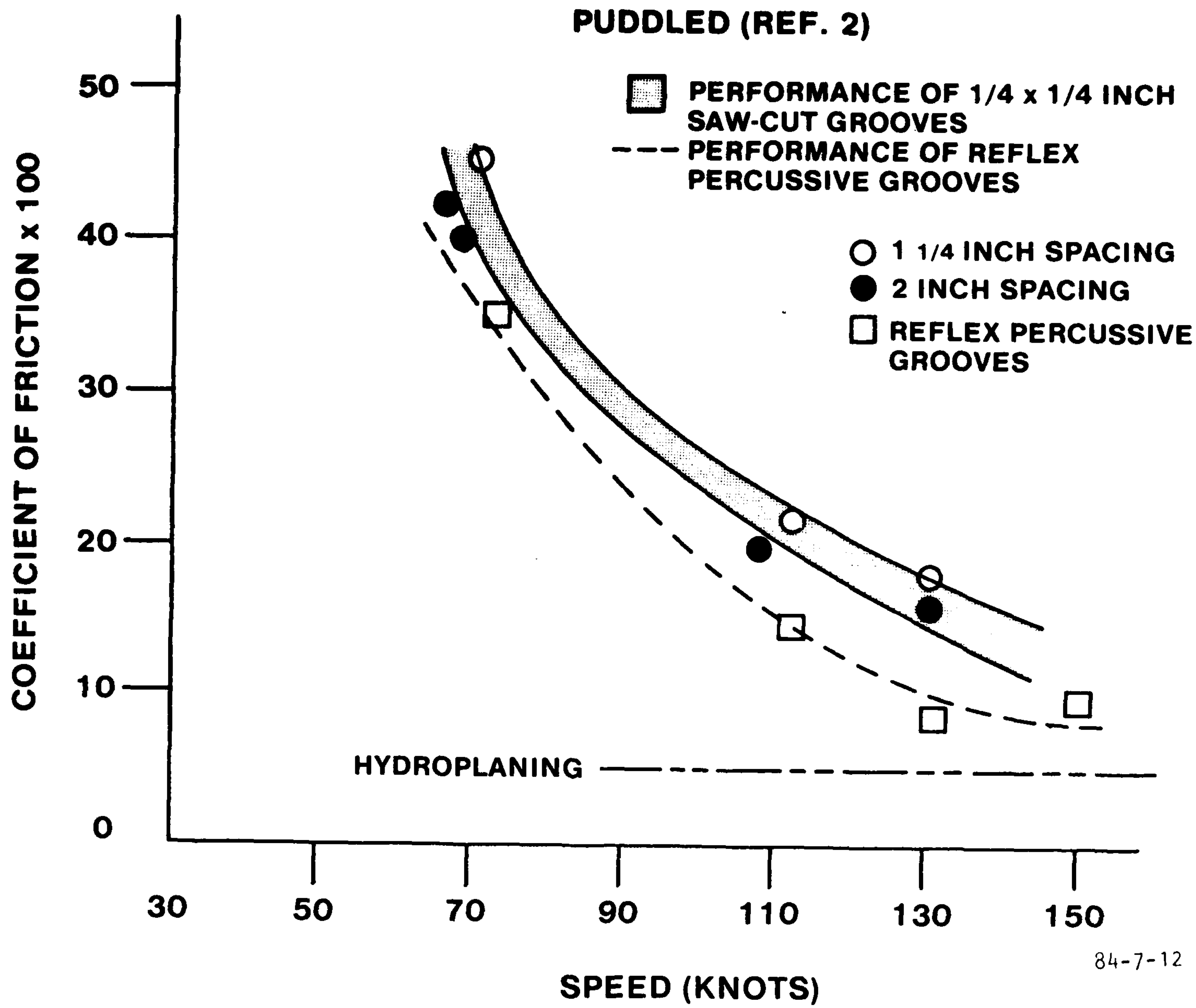

FIGURE 12. BRAKING PERFORMANCE OF A WORN TIRE ON PUDDLED SURFACES (FROM REFERENCE 2)

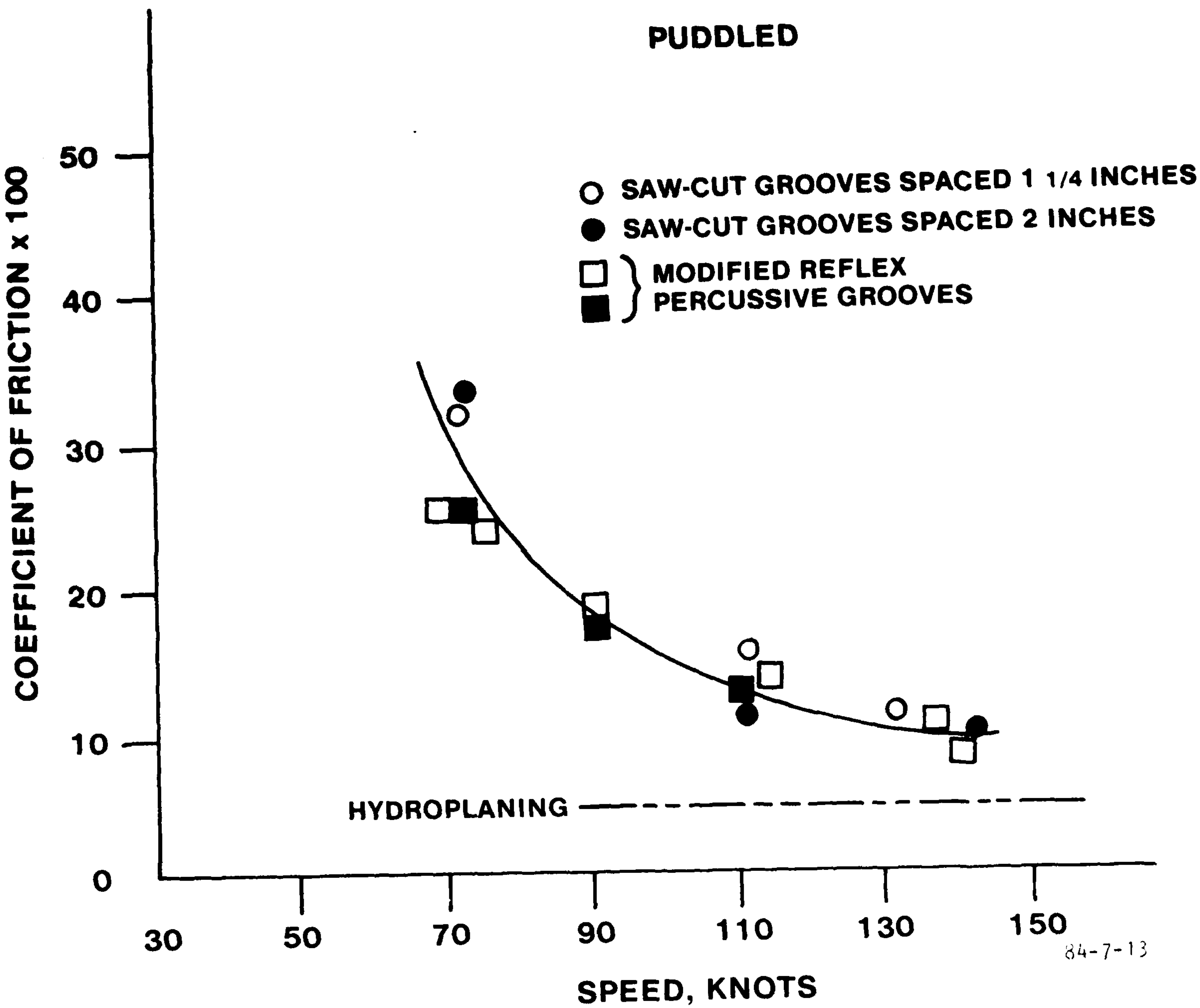

FIGURE 13. COMBINED BRAKING PERFORMANCE OF A WORN TIRE ON PUDDLED SURFACES